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ESTIMATION OF HISTORICAL POPULATION SIZE OF EASTERN SPINNER DOLPHINS

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ESTIMATION OF HISTORICAL POPULATION SIZE OF EASTERN SPINNER DOLPHINS

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ABSTRACT

An assessment of the status of the stock of eastern spinner dolphins (*Stenella longirostris orientalis*) in the eastern tropical Pacific is required by U. S. law under the Marine Mammal Protection Act, as they suffer mortality in the tuna purse-seine fishery that occurs in that region. Current estimates of abundance from research vessel surveys were used in combination with estimates of mortality from tuna vessel observer data to estimate the pre-exploitation or historical population size for the eastern spinner stock, using the back-calculation technique of Smith (1983). A range of values was used for the current population size, the maximum net recruitment rate (MNPL), z (the shape parameter that sets maximum net productivity level), and the number of animals killed relative to the estimated mortality. Relative population sizes (current population size divided by historical population size) ranged from 0.18 to 0.73. In most cases, relative population size was well below MNPL. Only 1 out of 42 parameter combinations resulted in a relative population size above MNPL. Using the best estimates for R_m, MNPL, and the level of mortality resulted in relative population sizes of 0.26 and 0.44 for the low and high current population estimates respectively, a range substantially below MNPL. These results indicate that the stock of eastern spinner dolphins is probably depleted.

INTRODUCTION

The stock of eastern spinner dolphins, *Stenella longirostris orientalis* (Perrin, 1990), is entirely contained within the oceanographic region of the eastern tropical Pacific. An assessment of the condition or status of this stock is required by U. S. law under the Marine Mammal Protection Act, as eastern spinners suffer mortality in the tuna purse-seine fishery that occurs in this region. One method for assessing the condition of a population is to estimate its pre-exploitation or historical abundance and compare an estimate of current population size to the historical size (Gerrodette and DeMaster, 1990). Smith (1983) described a method for back-calculating historical population size (N_h) from estimates of the current population size (N_c), the historical kill, the maximum net recruitment rate (R_m), and the maximum net productivity level (MNPL). He used this technique to estimate historical abundance for eastern spinners, resulting in estimates of relative population size (N_c/N_h) for 1979 ranging from 0.17 to 0.25.

Smith and Polacheck (1979) showed that for animals such as dolphins with a low R_m, the estimate of N_h is most sensitive to the estimate of N_c. Smith (1983) used an estimate of abundance of 293,000 animals based on combined data from aerial and research vessel surveys conducted in 1979 (Holt and Powers, 1982). Recently, the U. S. National Marine Fisheries Service conducted large-scale research vessel surveys annually for five years (1986-90) as part of the Monitoring of Porpoise Stocks (MOPS) program (Holt and

Sexton, 1990a; Holt and Sexton, 1989; Holt and Sexton, 1990b; Sexton, Holt, and DeMaster, 1991; Gerrodette and Wade, 1991). Unlike the 1979 survey, the MOPS surveys extensively covered the entire range of eastern spinners. Additionally, the 1979 data were analyzed using a method that could introduce considerable bias. For example, sightings were pooled across all dolphin species to calculate an effective strip width, and a pooled estimate of eastern and whitebelly spinner dolphin abundance was estimated, then divided between the two stocks according to the area occupied by each stock.

Relative abundance estimates from the MOPS data have been made (Holt and Sexton, 1990a; Holt and Sexton, 1989; Holt and Sexton, 1990b; Sexton, Holt, and DeMaster, 1991; Gerrodette and Wade, 1991). Given the increase in the quantity of data and the coverage of the eastern spinner stock area, these are probably more reliable than the estimates based on the 1979 data. These published relative abundance estimates for eastern spinners from the first four years of MOPS data ranged from 533,000 to 1,200,000 and were calculated by a method nearly identical to the 1979 method, which was designed to maximize precision at the expense of bias (Sexton, Holt, and DeMaster, 1991).

A re-analysis of all five years of MOPS data using different methods in which only eastern spinner sightings were used to estimate the abundance of the eastern stock resulted in estimates of abundance between 391,200 and 754,200 animals (Wade and Gerrodette, 1991). Although these estimates are provisionally still considered relative rather than absolute estimates of abundance, they are better estimates of absolute abundance than the estimates based on pooling sightings data for eastern and whitebelly spinner dolphins. Preliminary investigations indicated there were no major sources of bias in the estimation technique (Wade and Gerrodette, 1991).

Regardless of the method of analysis, the abundance estimates from the MOPS data were all greater than 293,000 for eastern spinners, ranging from approximately 1.3 to 4 times the 1979 estimate. Except at the very low end of this range, this was too great an increase to have occurred from population growth alone during the 7 to 11 years between surveys. It is therefore appropriate to repeat the back-calculation procedure for eastern spinners using the more recent estimates of abundance. N_h was thus calculated for a series of trials, using the low and high figures from the best available estimates of absolute abundance from Wade and Gerrodette (1991), and using the same range of parameter estimates as in Smith (1983). Additionally, the sensitivity of the estimate of N_h to errors in the estimates of dolphin mortality was investigated.

METHODS

POPULATION MODEL

The methods of Smith (1983) were duplicated, using the simple recursive relationship

$$N_{t+1} = N_t - K_t + R_t(N_t - 1/2K_t), \quad (1)$$

where t denotes the year; N, the abundance; K, the number of animals killed; and R, the net recruitment rate. Density-dependence is incorporated into the equation by the relationship

$$R_t = R_m[1 - (N_t/N_h)^z], \quad (2)$$

where z is a shape parameter that determines MNPL (see Smith, 1983). Equation 1 can be solved for N_t as a function of N_{t+1}, R_t, and K_t. Therefore, by specifying an initial population size, the number of animals killed in each year, the maximum net recruitment rate, and the maximum net productivity level, these two equations can be iteratively solved for N_h.

1986-90 POPULATION ESTIMATES

Abundance estimates for all five years of MOPS data were recently calculated (Wade and Gerrodette, 1991), and were considered (see IWC Report 42: Small Cetacean sub-committee report) the least biased estimates of absolute abundance for eastern spinners (Table 1). For the purposes of this study, the low and high estimates from Wade and Gerrodette (1991) were used as possible bounds for a single point estimate of population size during the interval 1986-90. These were 391,200 and 754,200 animals.

ESTIMATES OF R_m AND MNPL

The same range of values as in Smith (1983) was used for the maximum net recruitment rate and for the maximum net productivity level. Values used for R_m were 0.0, 0.03, and 0.06, which were thought to encompass the range of the greatest possible value of R_m for dolphins of *Stenella* spp. (Reilly and Barlow, 1986). Values used for MNPL were 50, 65, and 80 percent of historical population size (i.e., z values of 1.0, 3.482, and 11.216, respectively), which were also thought to encompass the range of actual values of MNPL for dolphins (Fowler, 1981).

ESTIMATES OF FISHERIES-CAUSED MORTALITY

Estimates of the number of eastern spinner dolphins killed in each year from 1959-1978 were taken from Smith (1983). Estimates of mortality for the years 1979-1987 were taken from the 1988 Annual Report of the Inter-American Tropical Tuna Commission, using the mortalities-per-set ratios. The back-calculation technique is fairly robust to imprecision or sampling variance in the mortality estimates when they are independent from year to year, as over and under-estimates tend to cancel each other out over the trajectory (Smith and Polachek, 1979). However, data from 1959-1972 are pooled due to small sample sizes, and are thus not independent. To encompass the probable range of actual mortality of eastern spinners, additional back-calculations were done using mortality values 120% and 80% of the mortality estimates for the entire time period, corresponding to a positive and negative bias of 20%.

STARTING YEAR FOR BACK-CALCULATION

The year 1988 was chosen as the starting point for the back-calculation since it was the mid-point of the series of years 1986-90. Because the largest possible R_m for dolphin populations is still a fairly low value and because the current level of take is of the same order of magnitude as R_m (DeMaster et al, 1991), relatively little population growth has probably occurred since 1979. Thus, the years 1980-1988 probably have little impact on the back-calculation results. As a check on this, the back-calculations were repeated for all parameter values using 1979 as the starting point. This repeats the calculations of Smith (1983) using 391,200 and 754,200 as the starting abundance rather than 293,000. The results confirm that differences from Smith (1983) were mostly due to the different starting abundance used rather than the different starting year.

RESULTS

Starting the back-calculation in 1988 (Table 2) versus 1979 (Table 3) generally had little impact on the estimate of relative population size (N_c/N_h). Most relative population sizes were within 0.01-0.02 for the same parameters run from the two different starting points (Tables 2 and 3). The largest effect of starting in 1988 versus 1979 occurred in the case of the greatest R_m paired with the greatest abundance estimate and the lowest mortality, where the additional 9 years of growth with relatively little mortality resulted in the relative population size being as much as seven percentage points closer to historical population size. Since the results from the two starting years were similar, only the 1988 results will be considered further.

Back-calculated trajectories resulting from different combinations of R_m, MNPL, N_c, and mortality estimates all declined until 1976, when the mortality decreased substantially (Figures 1-

6). In those trajectories where R_m equaled 0.06, population size increased significantly from 1976 to 1988, while with an R_m equal to 0.03, population size was relatively constant, increasing only slightly.

The impact of changes in the parameter estimates was consistent with Smith (1983). Greater estimates of R_m, MNPL, or the initial population size, and lower estimates of mortality all had the effect of increasing relative population size. A large change in relative population size occurred by changing the current abundance estimate. When an N_c of 391,200 animals was used, the current population was between 18 and 41% of historical population size. When an N_c of 754,200 animals was used, the current population was between 29 and 73% of historical population size. Only back-calculations using the higher population estimate exceeded the MNPL.

A large effect on relative population size also resulted from changing the mortality estimates. For example, at what may be considered the most probable parameter estimates of R_m equal to 0.03 and the MNPL equal to 65%, if one starts with 120% mortality at a starting population of 391,200, relative population size was 0.22. Changing the mortality to 80% and leaving the starting population at 391,200 changed relative population size to 0.31. Starting the population at 754,200 and 120% mortality changed relative population size to 0.38.

As reported in Smith (1983), there was a linear increase in relative population size with R_m (Figures 7-9). When comparing back-calculations using the same mortality estimates, the starting population size had a substantial effect. For example, the lowest value of relative population size starting from a population size of 754,200 animals was still more than the highest value of relative population size starting at 391,200. Decreasing the amount of mortality predictably increases the relative population size.

Changing the MNPL had a relatively small impact on relative population size, but the effect was greater with a greater R_m (Figures 10-12). Finally, comparing relative population size to MNPL indicates that nearly all of the parameter combinations resulted in relative population size values well below MNPL (Figures 10-12).

DISCUSSION

The estimates of historical population size varied between a low of approximately 1,000,000 to a high of about 2,500,000. The range of these estimates was not overly sensitive to the current estimate of abundance, ranging from 950,000 to 2,200,000 starting with an initial population size of 391,200, and 1,030,000 to

2,560,000 starting with 754,200. Except at the higher growth rate of 0.06, estimates of historical population size were generally within 200,000-300,000 of each other, given that only initial population size was allowed to vary. This parallels the results of Breiwick and Braham (1990), who reported that back-calculation of historical population size is insensitive to current population size when done over a long time period. Although Smith and Polacheck (1979) reported that the estimate of N_h for dolphin populations was most sensitive to the estimate of N_c over the range of parameter values possible for these dolphin populations, the influence of N_c diminishes relative to the influence of the mortality the farther back in time the population was projected. Because estimates of historical population size did not vary much with the current estimates of abundance, it follows that estimates of relative population size did vary significantly, as the different starting population sizes are divided by nearly the same estimate of N_h.

For most of the trajectories current population size was below 50% of historical population size. Exceptions to this occurred when 754,200 animals was used as the starting population size with an R_m of 0.06, or when 754,200 animals was used with an R_m of 0.03 and mortality levels of 80%. Additionally, the estimate of relative population size only exceeded the MNPL in one of the 42 parameter combinations, that of a starting population size of 754,200 animals, 0.06 R_m, and 80% level of mortality combined with an MNPL value of 50% (Figure 12). In this case, changing MNPL had little impact on whether the population was currently above or below MNPL, as relative population size increased proportionally with the change in MNPL.

The management status of the stock of eastern spinner dolphins would be defined as "depleted" if they are below the MNPL and "not depleted" if they are at or above the MNPL. Given the results from the range of realistic parameters used in this analysis, it is most likely that eastern spinner dolphins are currently below the MNPL. Only the combination of the most extreme parameter values creates a population trajectory which resulted in N_c exceeding the MNPL (Figure 6, lowest trajectory). This trajectory is not consistent with an independent estimate of the trend in abundance of eastern spinner dolphins from tuna-vessel data (Anganuzzi, Cattanach, and Buckland, 1991). Anganuzzi et al. (1991) reported that after 1975 there was a decrease in the population until about 1983, an increase until 1986, followed by another decrease until 1990. They indicated that the population in 1988 was approximately at the same level as in 1975. Thus, a trajectory that implies substantial growth since 1975 (total growth from 1975 to 1988 of 32% in the back-calculation which was not depleted) does not seem reasonable.

Smith (1983) estimated relative population size for the eastern spinner dolphin population for a variety of combinations of R_m and MNPL to be from 0.17 to 0.25 using a starting population

size of 293,000 animals and a mortality level of 100% of the reported estimates. Starting in 1988 and repeating his calculations with different starting populations resulted in relative population sizes from 0.21 to 0.60 (Table 2). These different results are not due to starting the back calculation in 1988, but are due to the higher starting population sizes (Table 3). Although the eastern spinner stock appears to be at a higher relative population size than reported in Smith (1983), the apparent status of the stock is unchanged from that result.

Incorporating possible bias in the mortality estimates increased the resulting range in relative population size to 0.18 to 0.73 (Table 2). The best range of estimates for relative population size using an R_m equal to 0.03, a MNPL equal to 65%, mortality levels of 100%, and the population estimates of 391,200 and 754,200 animals resulted in values of 0.26 and 0.44 respectively, a range substantially below the MNPL.

An improvement in the precision and bias of an estimate of absolute abundance for the eastern spinner population would allow a more definitive assessment of the status of the current population relative to historical, pre-exploitation levels.

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Table 1. Estimates of abundance (in thousands of animals) of the eastern spinner dolphin stock from MOPS data 1986-90 (Wade and Gerrodette, 1991).

Year	Estimate
1986	603.7
1987	444.7
1988	754.2
1989	748.8
1990	391.2

Table 2. Relative abundance (current/historic) for eastern spinner dolphins, starting the back-calculation in 1988.

Initial Abundance		391.2	391.2	391.2	754.2	754.2	754.2
% Mortality		120.0	100.0	80.0	120.0	100.0	80.0
Rmax	MNPL						
.00	--	.18	.21	.24	.29	.33	.38
.03	50	.20	.24	.28	.34	.39	.45
.03	65	.22	.26	.31	.38	.44	.52
.03	80	.23	.27	.33	.40	.47	.55
.06	50	.23	.27	.32	.39	.45	.52
.06	65	.26	.31	.38	.47	.55	.65
.06	80	.28	.33	.41	.51	.60	.73

Table 3. Relative abundance (current/historic) for eastern spinner dolphins, starting the back-calculation in 1979.

Initial Abundance		391.2	391.2	391.2	754.2	754.2	754.2
% Mortality		120.0	100.0	80.0	120.0	100.0	80.0
Rmax	MNPL						
.00	--	.18	.21	.25	.30	.34	.39
.03	50	.20	.23	.28	.33	.38	.44
.03	65	.22	.25	.30	.37	.42	.48
.03	80	.23	.27	.32	.39	.44	.52
.06	50	.22	.26	.31	.37	.42	.48
.06	65	.25	.29	.36	.43	.50	.58
.06	80	.27	.32	.39	.48	.56	.66

LIST OF FIGURES

1.) Eastern spinner dolphin back-calculated trajectories in thousands of animals, using seven combinations of R_m and MNPL, starting with 391.2 thousand animals in 1988. Lowest line is eastern spinner dolphin mortality in each year as 120% of mortality estimates.

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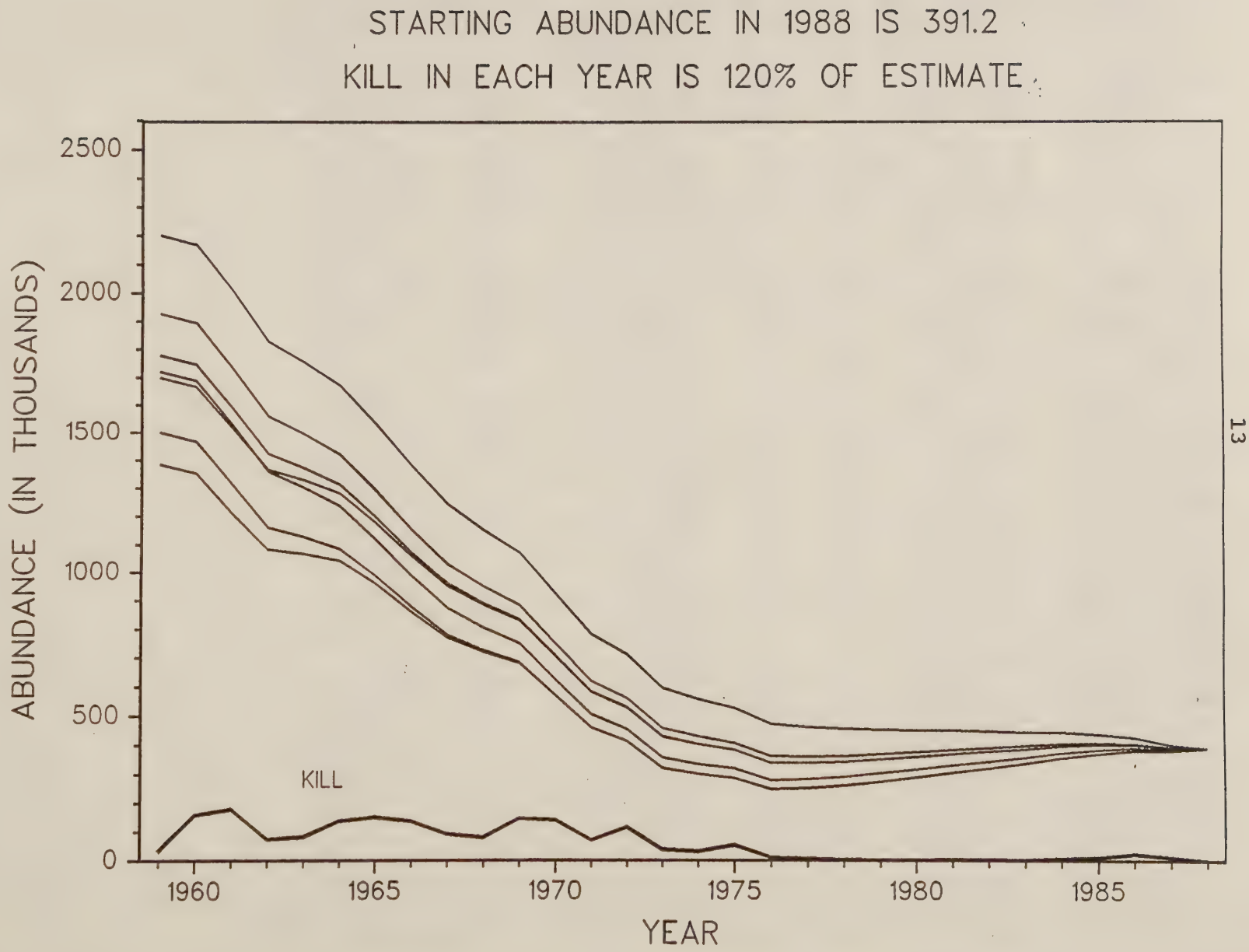
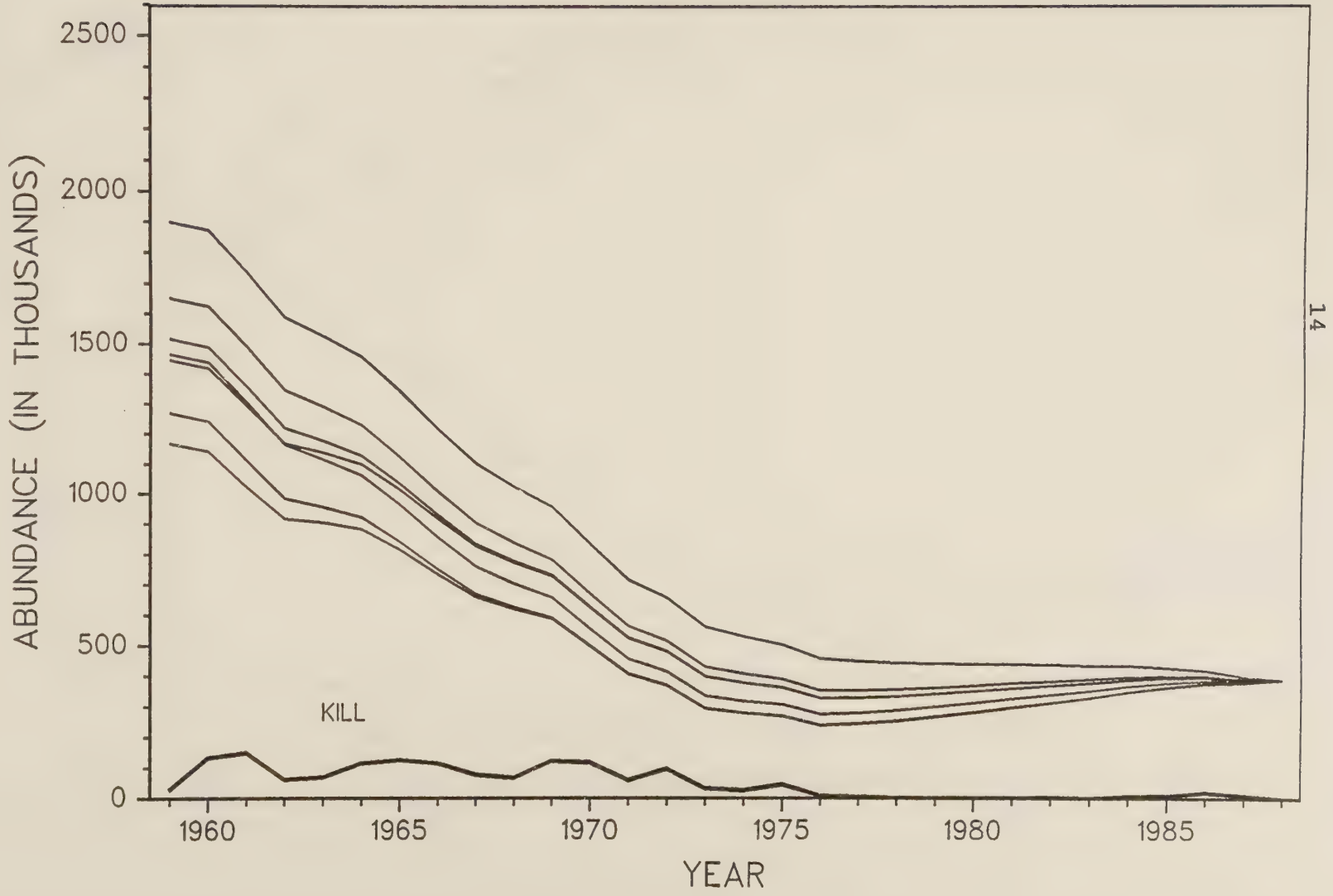
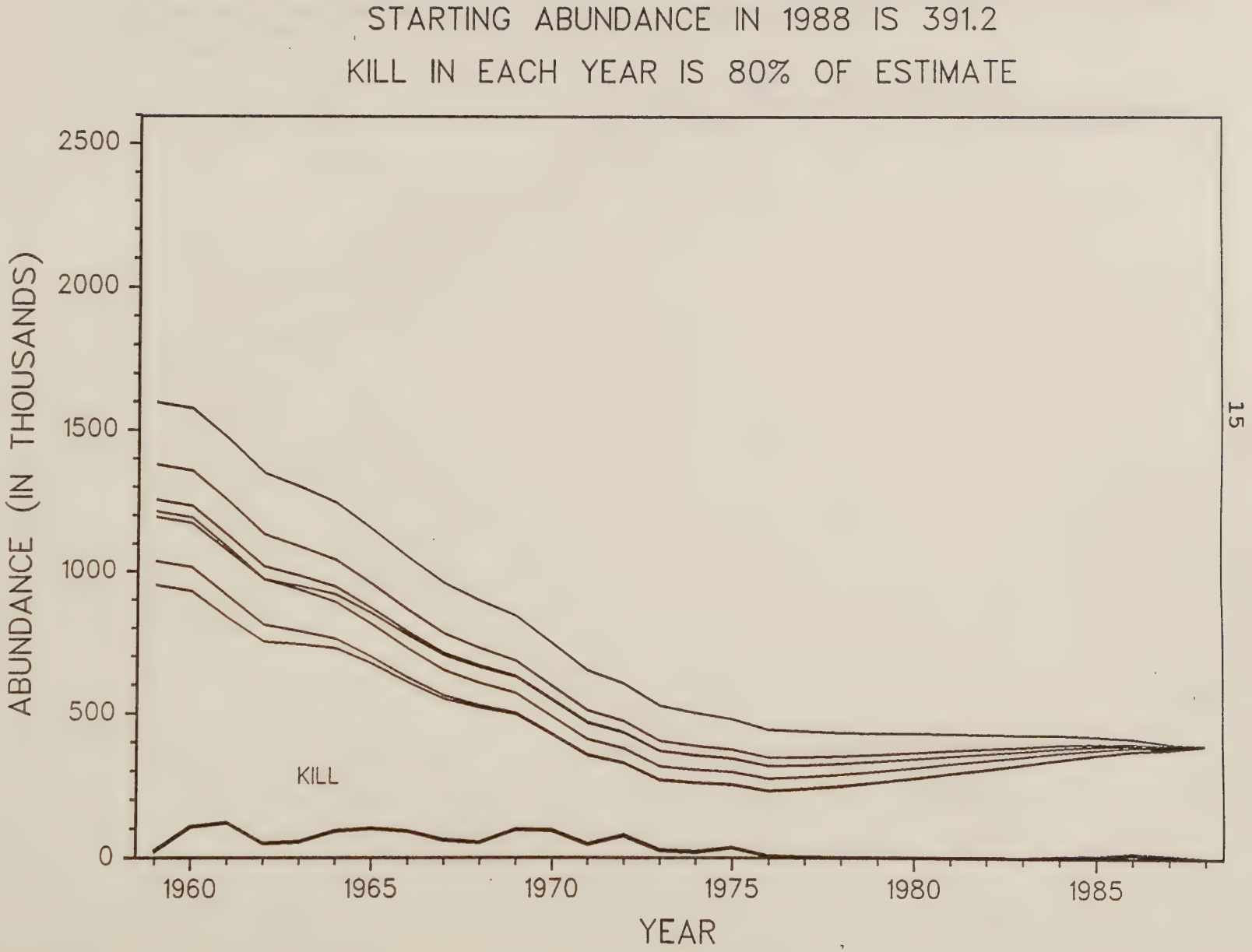
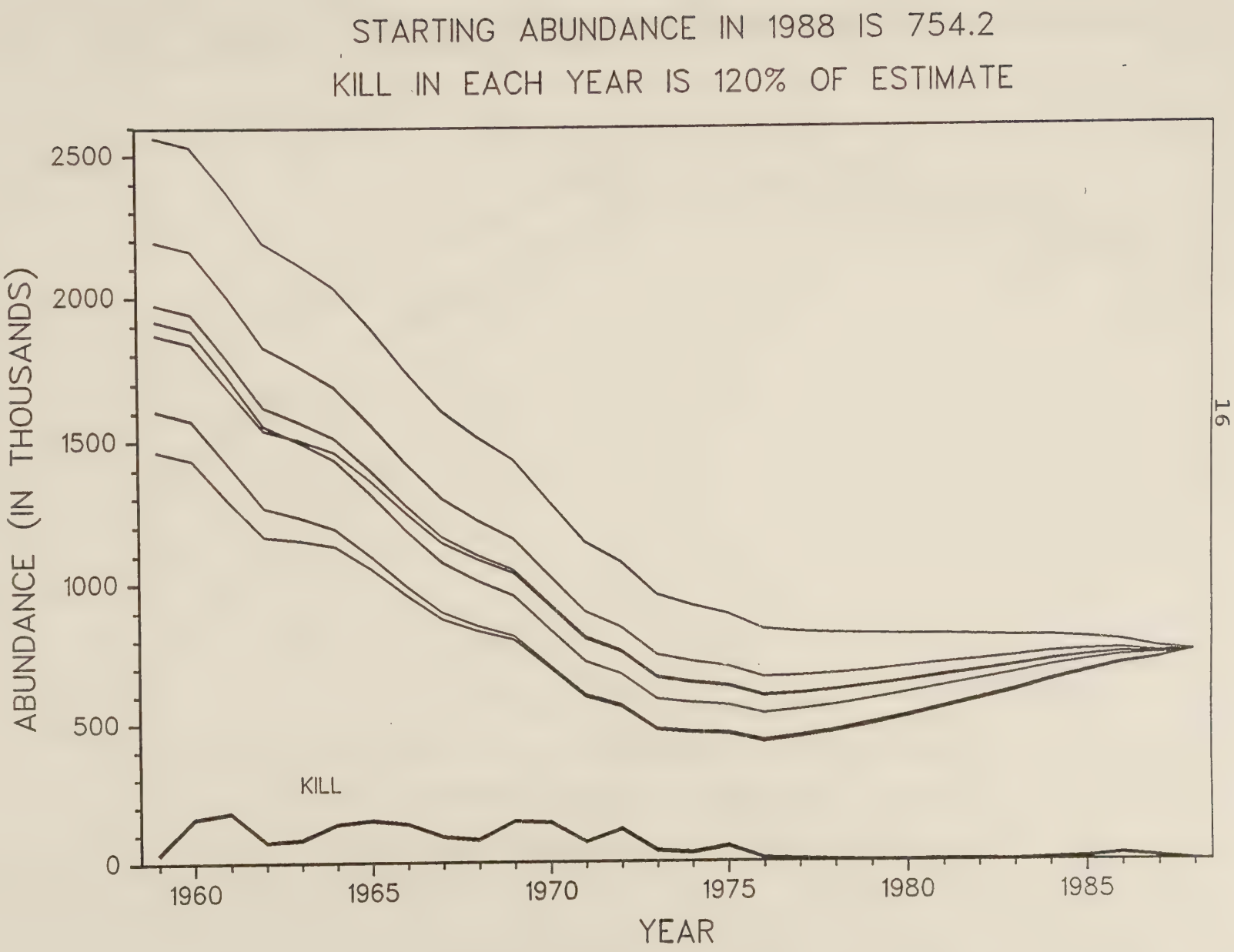
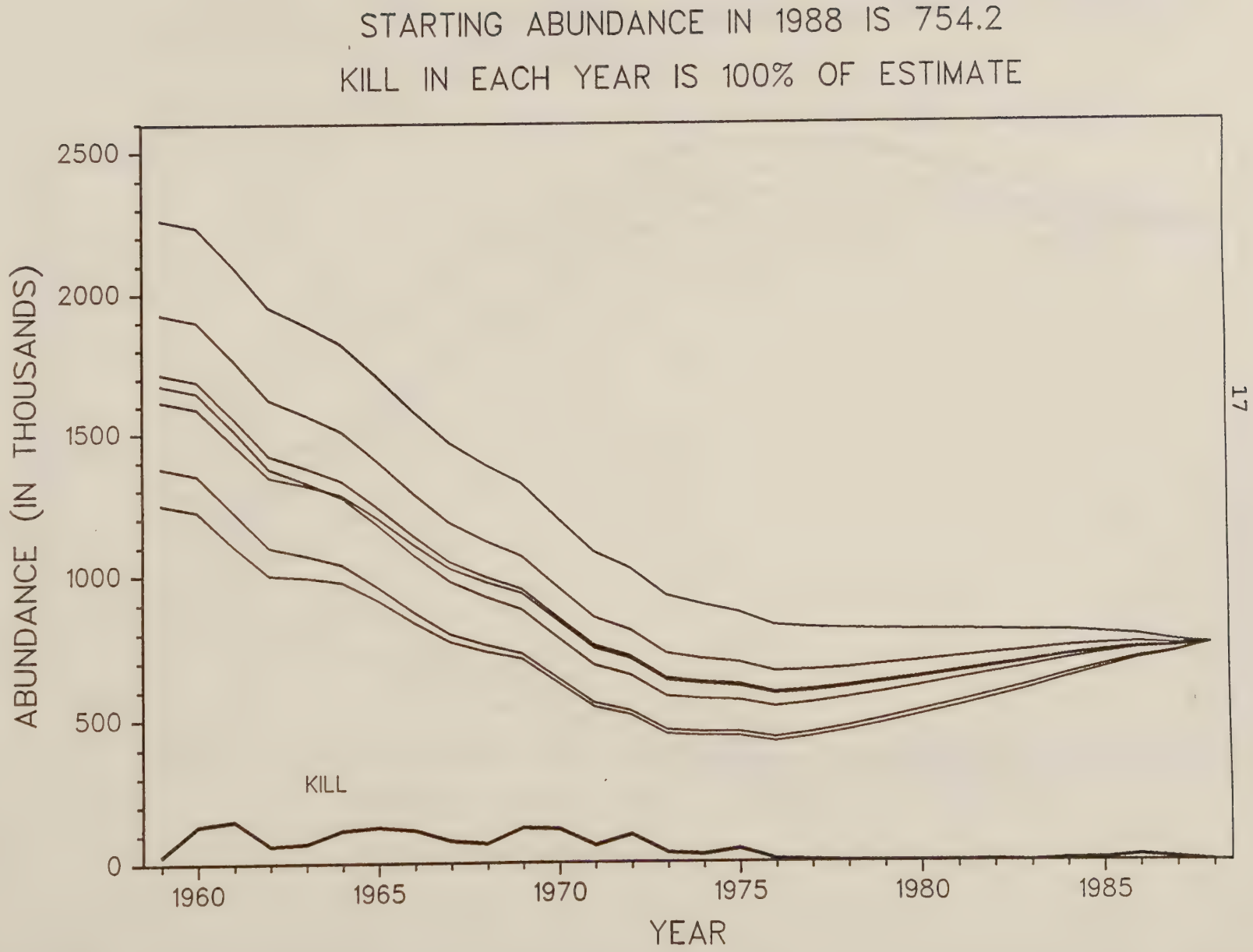
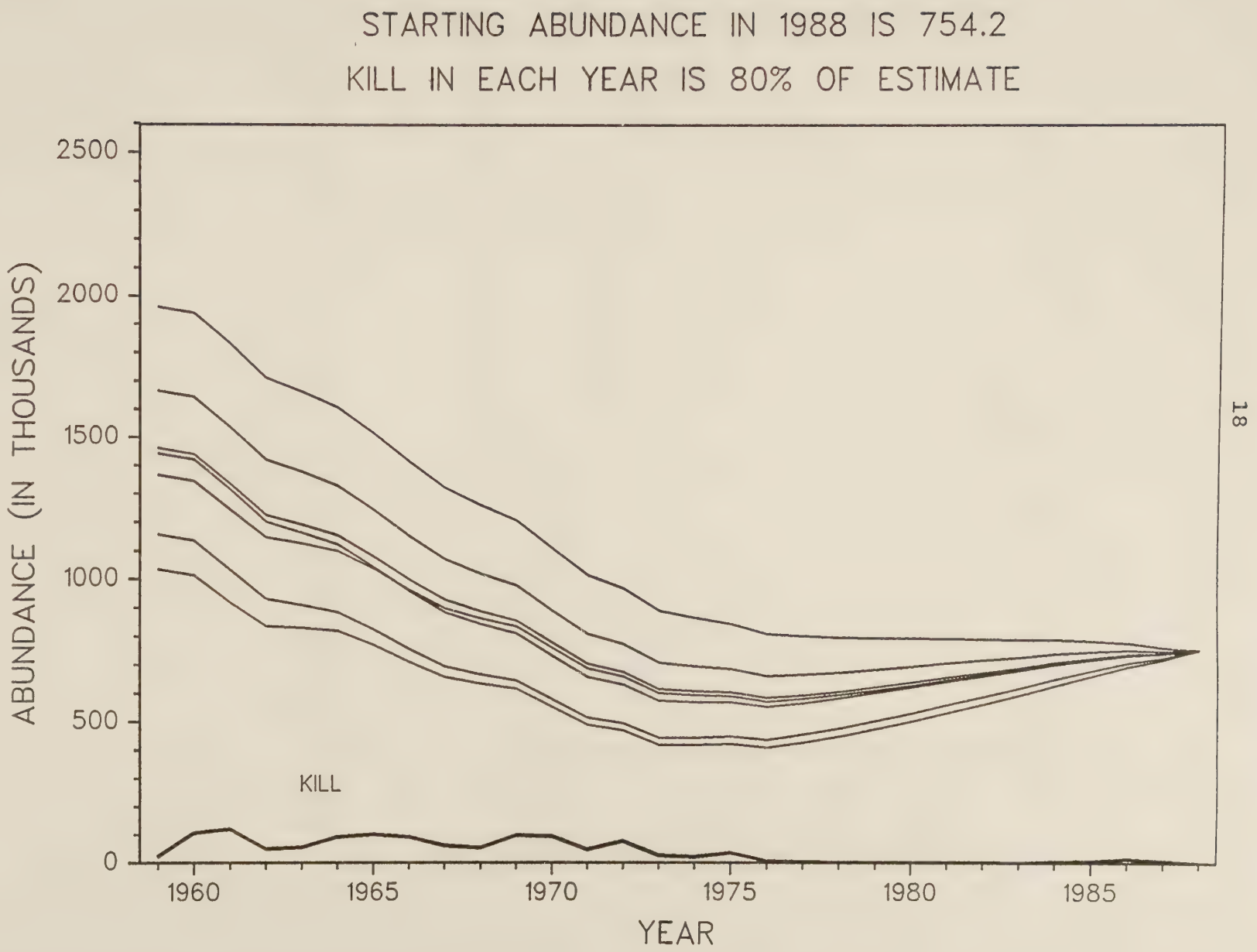

STARTING ABUNDANCE IN 1988 IS 391.2
KILL IN EACH YEAR IS 120% OF ESTIMATE
ABUNDANCE (IN THOUSANDS)
2500
2000
1500
1000
500
0
KILL
1960
1965
1970
1975
1980
1985
YEAR

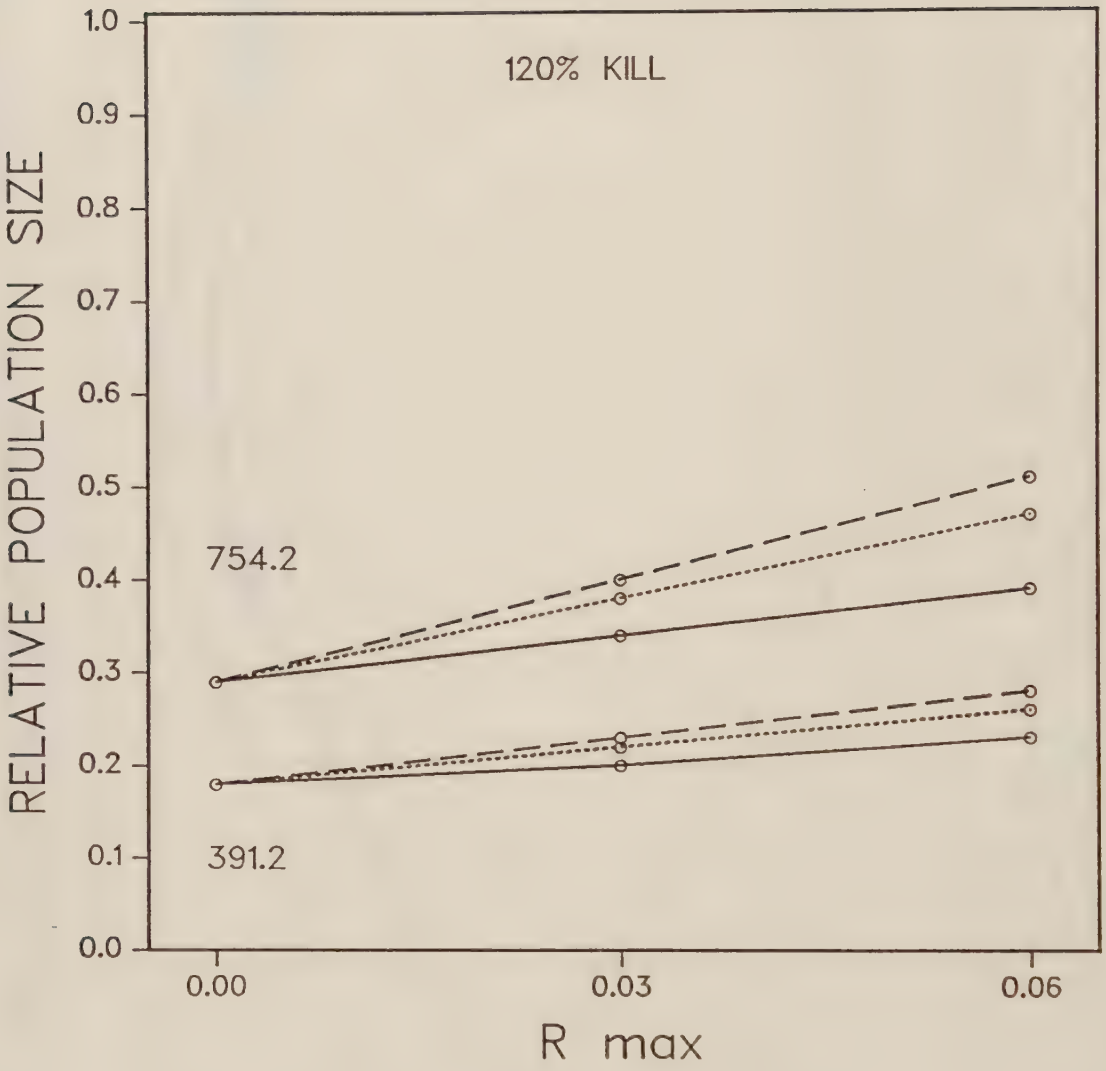

STARTING ABUNDANCE IN 1988 IS 391.2
KILL IN EACH YEAR IS 100% OF ESTIMATE
ABUNDANCE (IN THOUSANDS)
2500
2000
1500
1000
500
0
KILL
1960
1965
1970
1975
1980
1985
YEAR

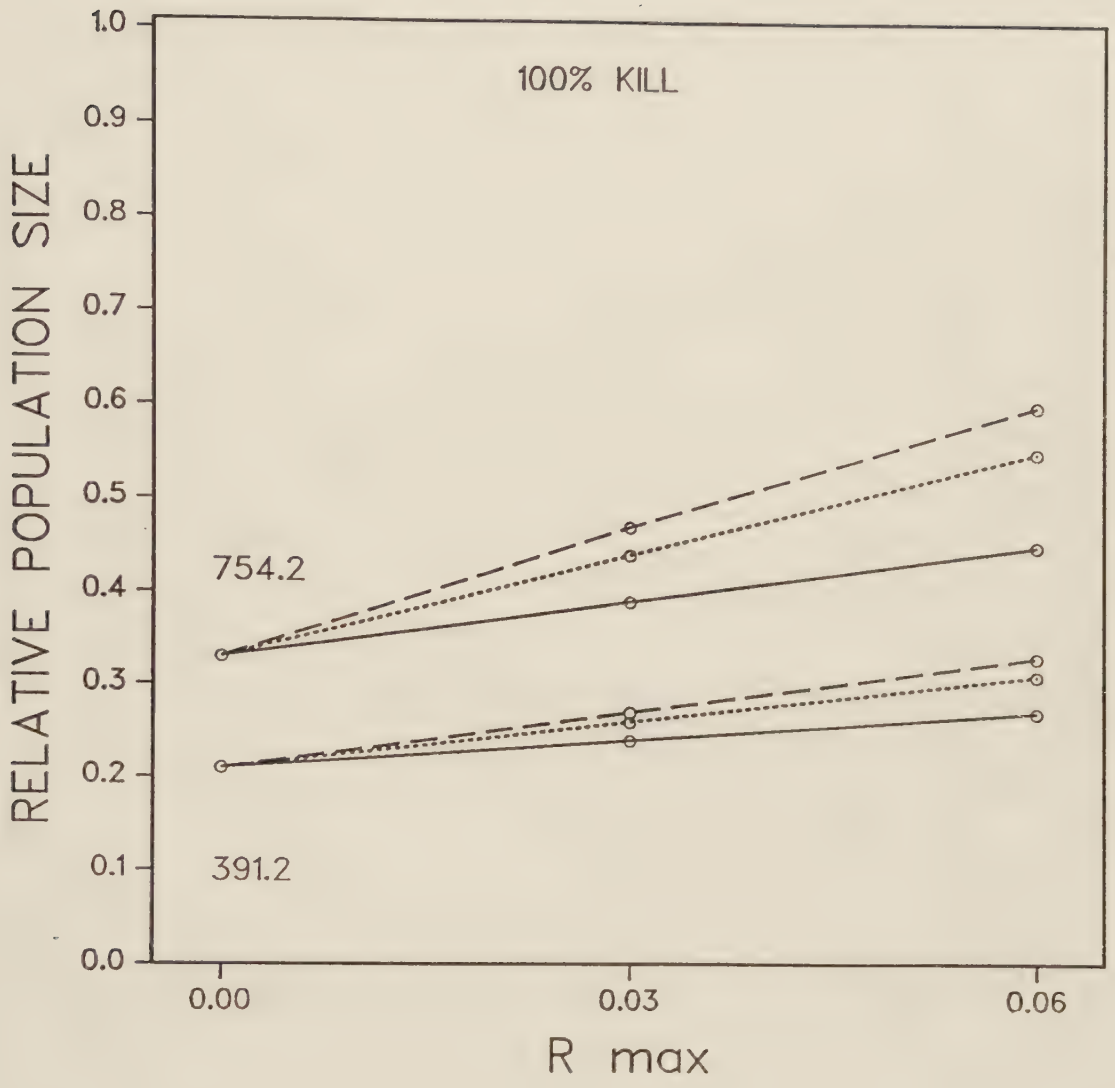

STARTING ABUNDANCE IN 1988 IS 391.2
KILL IN EACH YEAR IS 80% OF ESTIMATE
ABUNDANCE (IN THOUSANDS)
2500
2000
1500
1000
500
0
KILL
1960
1965
1970
1975
1980
1985
YEAR

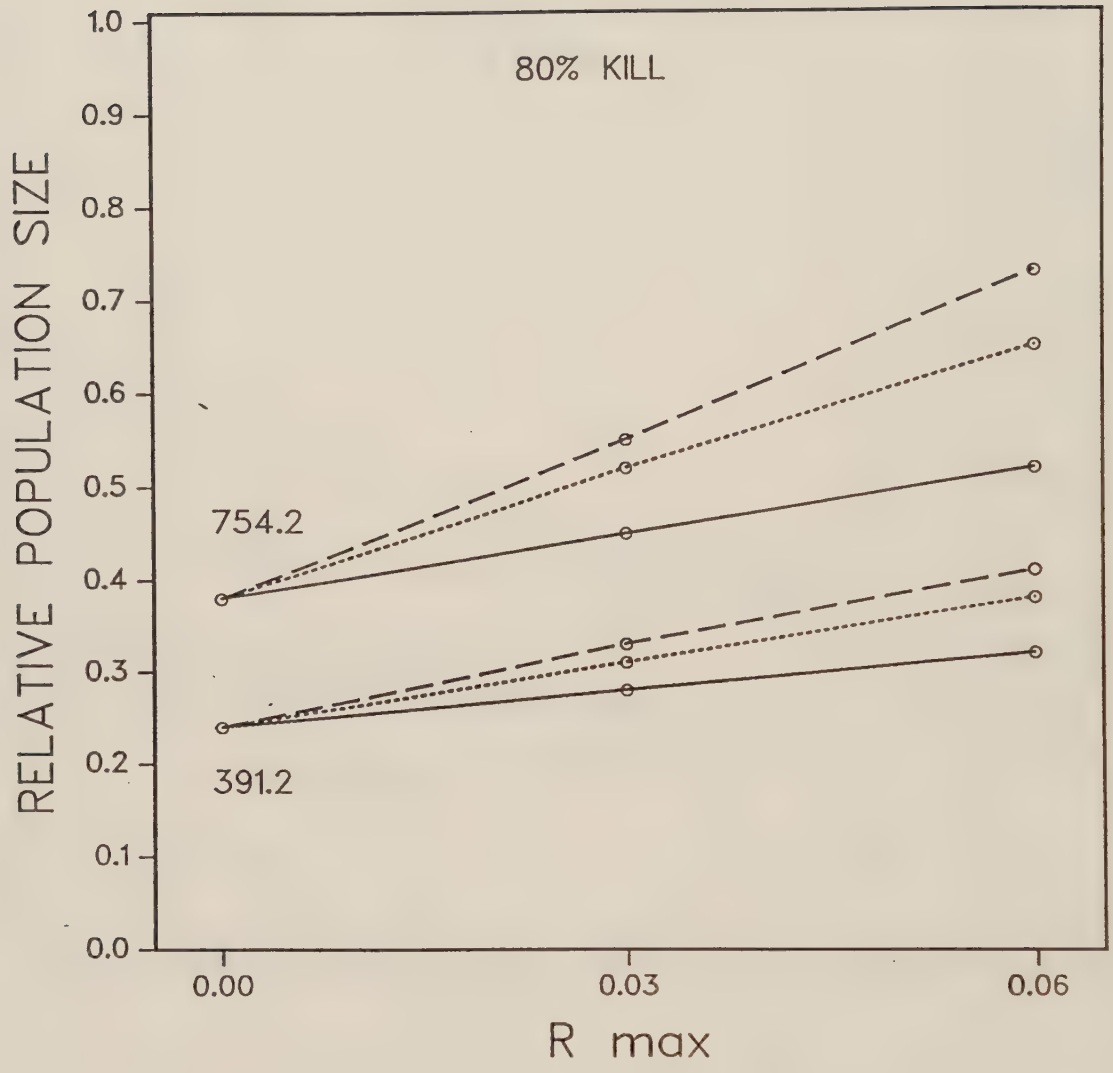

STARTING ABUNDANCE IN 1988 IS 754.2
KILL IN EACH YEAR IS 120% OF ESTIMATE
ABUNDANCE (IN THOUSANDS)
2500
2000
1500
1000
500
0
KILL
1960
1965
1970
1975
1980
1985
YEAR
16

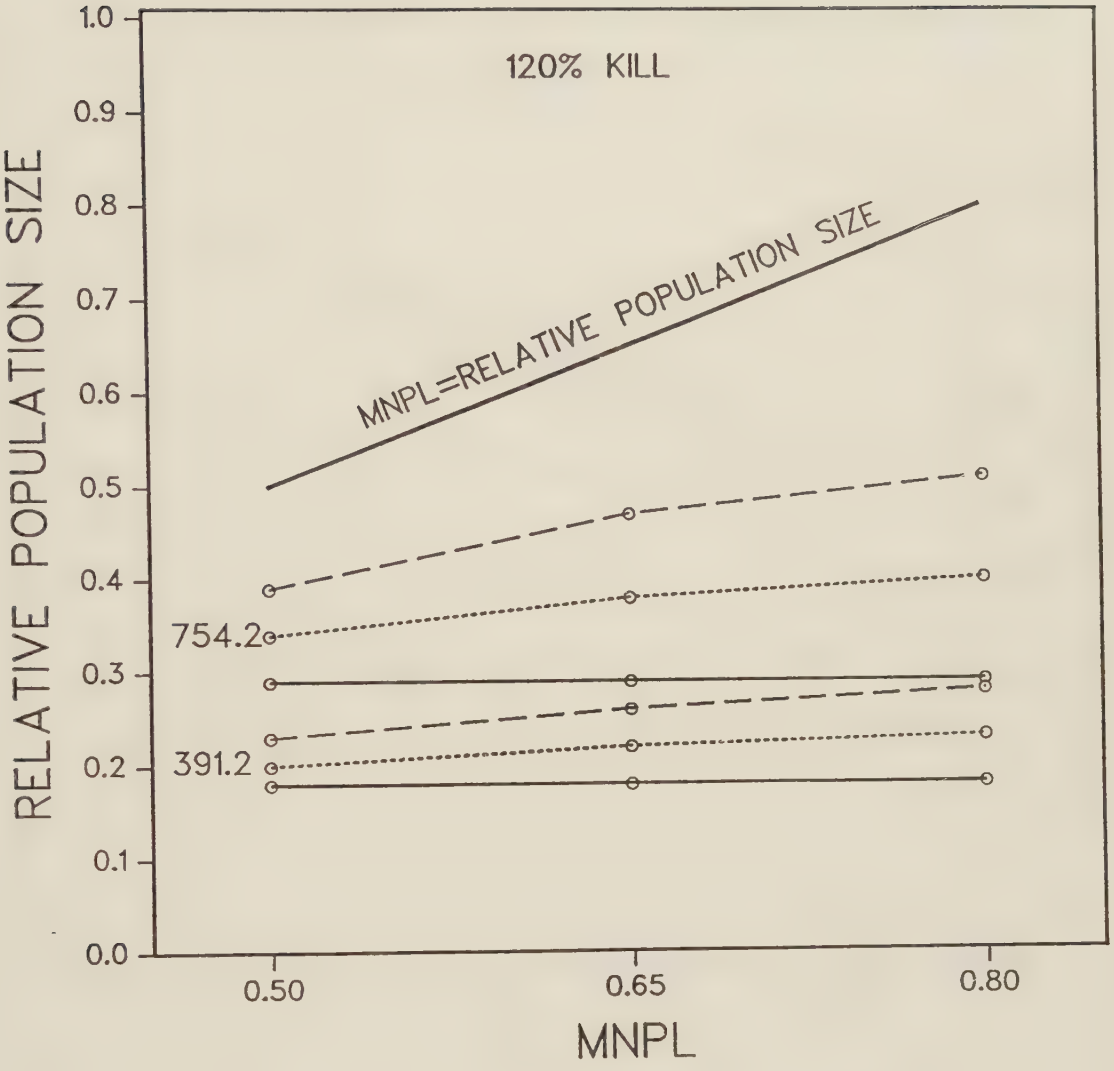

STARTING ABUNDANCE IN 1988 IS 754.2
KILL IN EACH YEAR IS 100% OF ESTIMATE
ABUNDANCE (IN THOUSANDS)
2500
2000
1500
1000
500
0
KILL
1960
1965
1970
1975
1980
1985
YEAR

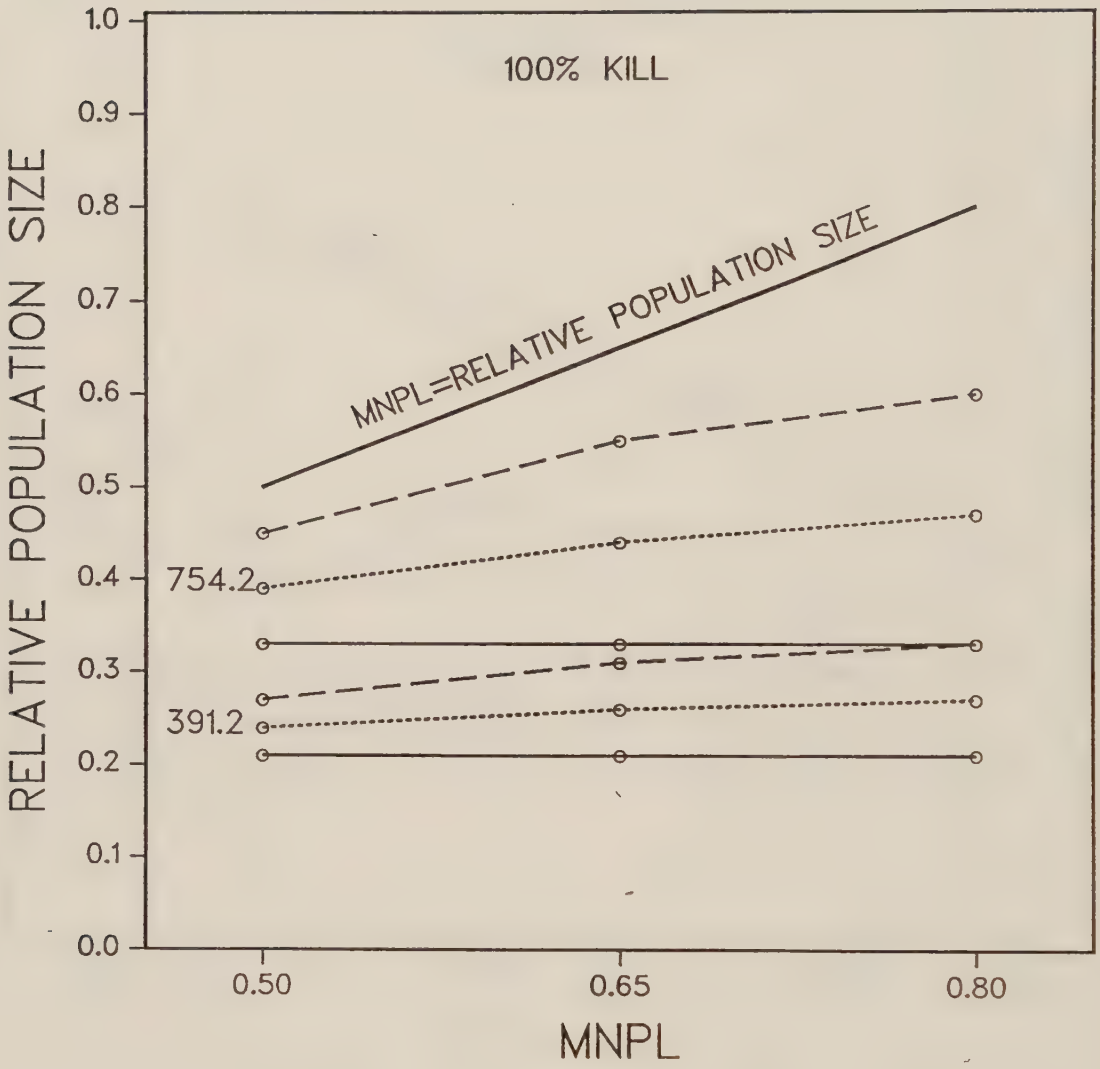

STARTING ABUNDANCE IN 1988 IS 754.2
KILL IN EACH YEAR IS 80% OF ESTIMATE
ABUNDANCE (IN THOUSANDS)
2500
2000
1500
1000
500
0
KILL
1960
1965
1970
1975
1980
1985
YEAR

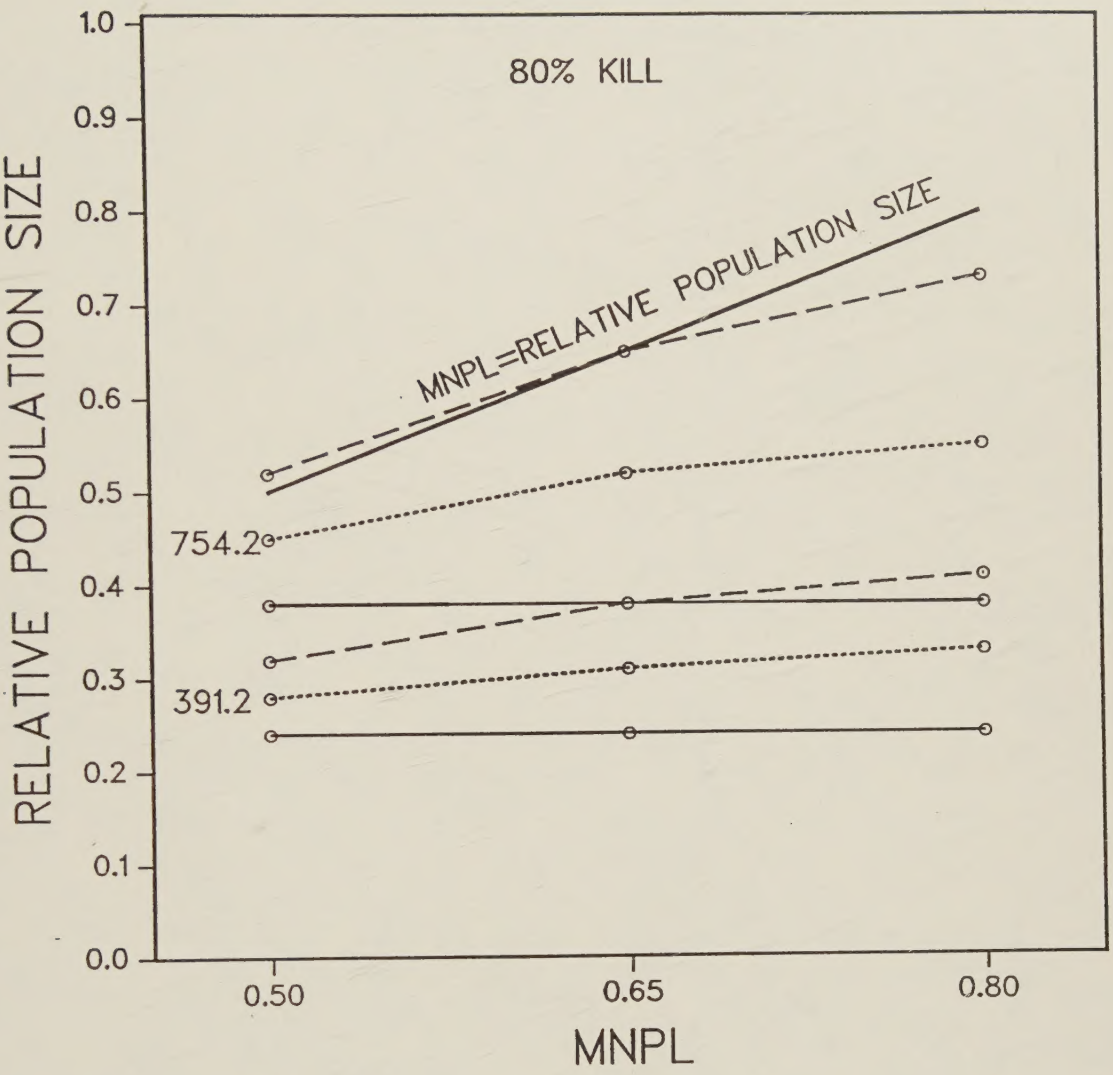

120% KILL
RELATIVE POPULATION SIZE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
754.2
391.2
0.00
0.03
0.06
R max


100% KILL
RELATIVE POPULATION SIZE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
754.2
391.2
0.00
0.03
0.06
R max


80% KILL
RELATIVE POPULATION SIZE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
754.2
391.2
0.00
0.03
0.06
R max


120% KILL
MNPL=RELATIVE POPULATION SIZE
754.2
391.2
RELATIVE POPULATION SIZE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.50
0.65
0.80
MNPL


100% KILL
MNPL=RELATIVE POPULATION SIZE
754.2
391.2
RELATIVE POPULATION SIZE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.50
0.65
0.80
MNPL


80% KILL
MNPL=RELATIVE POPULATION SIZE
754.2
391.2
RELATIVE POPULATION SIZE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.50
0.65
0.80
MNPL